USING GLEAMS TO SELECT ENVIRONMENTAL WINDOWS FOR HERBICIDE APPLICATION IN FORESTS[1]

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ABSTRACT

Observed herbicide runoff and groundwater data from a pine-release herbicide application study near Gainesville, Florida were used to validate the GLEAMS model hydrology and pesticide component for forest application. The study revealed that model simulations agreed relatively well with the field data for the one-year study. Following validation, a modified version of GLEAMS was applied using a 50-year climatic record to determine the periods (windows) for least water quality degradation within the Forest Service's recommended application window for best vegetation control. The pesticide component of GLEAMS was modified to simulate up to 245 pesticides simultaneously. Four herbicides commonly used in the region to control competing vegetation were represented in the model study. Within the application windows for each herbicide, the best application dates, or "environmental" windows were determined to minimize environmental effects for each location. Results of the simulation study are tabulated in the paper for use in the forest industry.

INTRODUCTION

The forest industry in the southeastern United States has successfully used herbicides during the last 10 years to control competing grass and herbaceous vegetation in site preparation for pine (Pinus sp.) plantings and in pine release (Michael et al., 1990). Vegetation control alone and in combination with fertilization has resulted in significant increased pine growth (Neary et al., 1990). Runoff studies have been conducted at a number of locations to measure losses of herbicides to streamflow following site treatments (Michael and Neary, 1993). Field studies of herbicide fate cannot be replicated on the same site in successive years. Efficacy studies have been made to determine the best time period for herbicide application for vegetation control. Results of these studies have been used to estimate the "best" interval within the longer time interval (Miller and Bishop, 1989). The one-time herbicide application on a specific field site does not allow evaluation of climatic and environmental consequences of variable application dates.

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A mathematical model called GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) was developed by Leonard et al. (1987) to assess the complex interactions of soil-climate-management for field-size areas on a long-term basis. Although GLEAMS was developed primarily for crop and pasture lands, Nutter et al. (1994) added an option to consider application on forest sites as well. GLEAMS model applications have been made to assess the long-term environmental impact of insecticide use in Southeastern forests (Nutter et al., 1993).

GLEAMS has been validated for agricultural crops (Leonard et al., 1987), and for forested areas (Nutter et al., 1993). A study is currently underway to evaluate forest streamside management zones at the locations included in this paper. Although the results have not been published, the model simulations made thus far compare favorably with observed measurements of runoff and pesticide losses.

Leonard et al. (1992) made 50-year GLEAMS simulations to examine the probabilities of year-to-year pesticide losses for a 20-day planting window for corn (Zea maize, L.). These were compared with 50-year means and standard deviations to consider potential for extreme or "worst case" situations.

The purpose of this paper is to demonstrate the use of the GLEAMS model to determine the best herbicide application periods to minimize potential environmental impacts. A location was selected in the Atlantic Coastal Flatwoods of peninsular Florida where a forest herbicide study provided data for model comparison (Smith et al., 1993). GLEAMS model simulation results are compared with observed data, and a nearby 50-year climatic record was used to determine the best "environmental" window within the "application" window for management recommendations.

METHODS OF ANALYSES

The GLEAMS model was developed to assess edge-of-field and bottom-of-root-zone loadings of water, sediment, and chemicals for comparing alternate management strategies using long-term simulation results. GLEAMS is a continuous simulation model with a daily time step, and consists of hydrology, erosion, pesticide, and plant nutrient components. The hydrology component uses daily climatic data and simulates the water balance components including surface runoff and percolation below the root zone. The erosion component computes soil detachment and sediment transport to the edge of the field. The pesticide and plant nutrient components compute pesticide, nitrogen, and phosphorous transformations, and calculates their transport in the solution and adsorbed phases. Up to 10 pesticides can be represented in a single simulation. Comparisons of long-term simulation results enable the user to make sound management decisions based upon relative loadings. Alternatives that can be evaluated include selection of herbicides and the method and dates of application. GLEAMS model version 2.10 was modified to consider up to 245 pesticides simultaneously in a single computer run. This modification made it possible to consider 1 pesticide applied on as many as 245 days by naming the pesticide with successive numbers and using the same pesticide characteristics for all applications. For example, Roundup was applied on day 1 of the application window as Roundup 1, Roundup 2 was applied on day 2 of the window, and so on to Roundup 245, each with the same characteristics. It is recognized that herbicide half-life may change due to climatic differences within the application window, but the same values were used throughout the window. Losses for each herbicide were kept separate in the simulation and reported separately. Model output includes annual losses and the final total losses in runoff, adsorbed onto sediment, and in percolation.

Herbicide applications are not made each year, but climate is different every year. The model was applied for 50 consecutive years of observed climate, but the same cover (canopy) was assumed for each year. In essence, this gives one treatment and 50 replications in time. The final results represent a significant sample of year-to-year variations in herbicide losses due to changes in climate.

The USDA-Forest Service conducted herbicide efficacy and fate studies in the southeastern United States for site preparation for pine planting and for pine release from competing vegetation. Four herbicides are commonly used for weed and brush control in the region. Pesticide characteristics, soil, and climatic region are factors in determining which herbicide may give the most effective control yet pose the least potential environmental degradation. All herbicides are not applied at each 1-year study site. Characteristics of the four herbicides, their application (efficacy) window, and recommended application rates are given in Table 1. Table 1 also includes the characteristics of the herbicide Garlon (TRICLOPYR) used at the selected study site in Alachua County, Florida.

Four-hectare plots at the study site northeast of Gainesville, Florida were surrounded by drainage ditches approximately 2 m deep and 3 m wide. A flume equipped with a continuous water-level recorder was installed at the outlets of the drainage ditch for discharge measurement. Samples of the discharge were taken during and between storm events for analysis of Garlon (Bush et al., 1990). Shallow groundwater observation wells were installed within the plots to monitor depths to water table and sampling for herbicide determination. The soil on the plots is Pomona fine sand (Ultic Haplaquods, sandy, siliceous, hyperthermic, uncoated), with a surface slope of 0.5%.

Table 1. Herbicide characteristics, and application windows and recommended rates for GLEAMS model simulation.

Herbicide Trade Name COMMON NAME	Water Solubility mg/l	K_{oc} l/g	Half-life Soil days	Half-life Foliage days	Wash-off Fraction	Application Window	Application Rate[a] kg/ha
Arsenal IMAZAPYR	11,000	100	65	30	0.90	5/1-10/31	2.24
Oust SULFOMETURON METHYL	70	78	20	10	0.65	2/1-5/31	0.42
Roundup GLYPHOSATE AMINE	900,000	24,000	47	3	0.60	8/1-10/31	5.60
Velpar-granules HEXAZINONE	33,000	54	77	[b]	[b]	2/1-4/30	1.68
Garlon TRICLOPYR ESTER	23	780	46	7	0.90	4/20-10/10	1.81

[a] Application rate of active ingredient for site preparation. [b] Not applied on foliage.

RESULTS AND DISCUSSION

Available data were used to develop parameter files for the GLEAMS model simulation for the Garlon study. Soils data were taken from published data (Carlisle et al., 1988) since local data were not available. Herbicide characteristics shown in Table 1 were supplied by the manufacturer. Rainfall was measured at the site for the 4-year study period, 1986-89. Monthly temperature and radiation data were obtained from climatological data at Gainesville.

Runoff (ditch flow) was observed from a 42 mm rainfall event 38 days after Garlon application on October 24, 1986. Runoff samples had Garlon concentrations of 1-2 ppb, with the maximum occurring on the second day (Bush et al., 1988). The small volume of observed runoff along with the Garlon concentration data indicate that the observed flow could have resulted from rainfall in the ditch during the high water table condition and from lateral subsurface flow above the spodic layer. Subsurface flow would be delayed (possibly second day) compared with direct surface runoff. Likewise, subsurface flow containing Garlon from near the channel on the day of the storm could be diluted by the rainfall on the channel compared with subsurface flow on successive days.

The GLEAMS model did not simulate surface runoff in 1986, and Garlon was not simulated to percolate below the 1 m effective root zone. Groundwater samples in the plot did not show Garlon concentrations above the detection limit of 0.7 ppb. Runoff was simulated with GLEAMS in 1988 when about 10 cm was reported (Riekerk, 1989). Again, the reported "runoff" volume could have included both rainfall in the drainage channel and lateral subsurface flow from the plot.

GLEAMS is not intended to be an absolute predictor of water, sediment, and chemical losses. However, the comparison made in the present study indicates the model gives "ballpark" results using published pedon data rather than site-specific soils data. This indicates the model is a useful tool for relative comparisons such as herbicide losses during application windows.

Fifty-year (1925-74) simulations were made for the site for each herbicide listed in Table 1. Since GLEAMS does not consider pesticide toxicity and the health advisory levels do not apply at field's edge or bottom of root zone, only herbicide losses can be examined in this study. Losses with runoff, sediment, and percolation are expressed as percentage of application rate, and are therefore unitized.

A 3-D graph was plotted for each herbicide to show year-by-year losses as a function of application date. Rainfall distribution within the year was reflected in the graphs. Only a simple example with a 2-D graph is shown here to illustrate the procedure. The simulated 50-yr average losses of Arsenal and Velpar granules are shown in Figure 1 by day within the application window. The application window for Velpar granules is 89 days, February 1 to April 30, and for Arsenal is 184 days, May 1 to October 31. Even though the beginning dates are different for the two herbicides, both are shown in the same figure for demonstration purposes. The 50-year simulation resulted in a total of 18 cm runoff for the entire period, or an average of less than 4 mm/year compared with about 0.7 mm for the one year of the Garlon study. Due to the soil-climate-pesticide interactions negligible runoff losses of Arsenal and Velpar were predicted. The losses shown in Figure 1 are essentially all percolation losses below the root zone. Only traces of runoff losses, about 0.01%, were simulated for Roundup and Oust.

In Fig. 1, low, essentially uniform, losses of Arsenal are simulated over the entire 184-day application window. Therefore, there is not a "best" environmental window, that is, there is no time in the 184 days in which simulated losses are significantly lower than any other time. The simulated Velpar losses are lowest at about 70 days into the application window. The best environmental window could be taken as the approximate 2-week period April 5-17 based upon the 50-year simulation results. The recommended application windows and windows for best control (Miller and Bishop, 1989), and the best environmental windows are summarized for the four herbicides in Table 2.

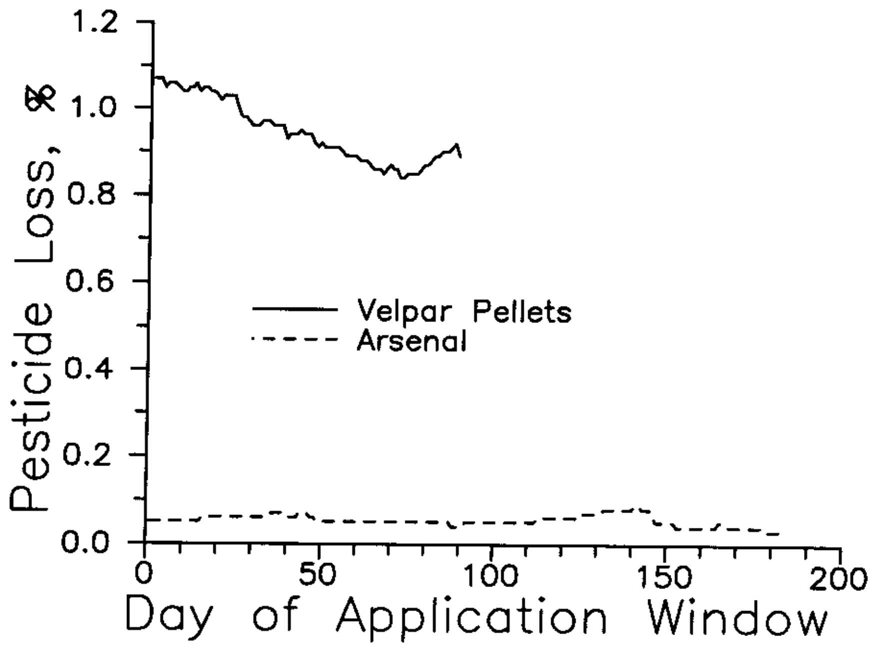

Figure 1. Pesticide loss as percent of application for 50-year GLEAMS model simulation for Pomona fine sand by day of application window: Velpar pellets--89 days beginning February 1; Arsenal--184 days beginning May 1.

Table 2. Herbicide application windows based upon 50-year average runoff, sediment, and percolation losses compared with "best" window for vegetation control.

Window	Herbicide			
	Arsenal	Oust	Roundup	Velpar granules
Application	5/01 - 10/31	2/01 - 5/31	8/01 - 10/31	2/01 - 4/30
Best control	7/01 - 9/30	3/05 - 4/10	8/01 - 10/20	3/05-4/25
Environmental (Alachua Co., FL)	9/24 - 10/31	2/01 - 5/31	8/01 - 10/31	4/05 - 4/17

Simulated year-to-year differences in Velpar loss are shown in Fig. 2. The first day of the application window for Velpar granules, February 1 (Table 1), was selected to demonstrate the variation. The 50-year mean loss for applications on February 1 of each year, 1.07% (Fig. 1), is plotted in Fig. 2. The total loss each year for the February 1 application is shown in Fig. 2. Losses range from a zero low to a maximum of 6.7% in the first 4 years of the 50-year period. Doubtless the high loss in year 4 resulted from significant rainfall on or shortly after the February 1 application date. It was stated above that herbicide applications are made in only one year for site preparation, and therefore field studies are conducted only for that one year. It can be seen from Figure 2 that misleading conclusions might be drawn from field data if the study was conducted in the first year (1925) compared with a study conducted in the fourth year (1928). Another series of differing years occurs from the 40th to the 44th years of simulation. This vividly portrays the significance of long-term simulations with a model such as GLEAMS.

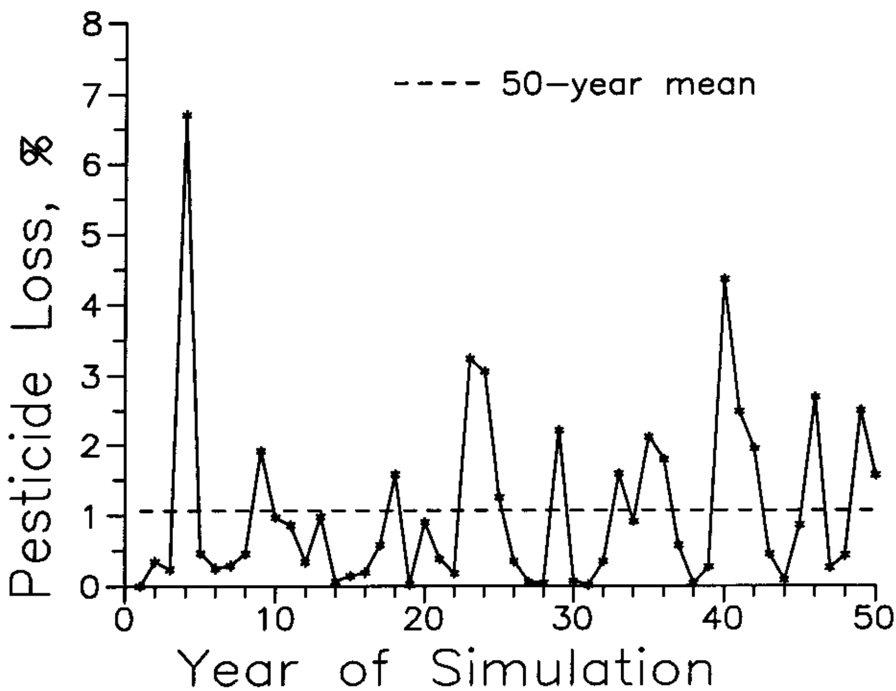

Figure 2. GLEAMS model simulated Velpar loss as percent of February 1 application for each of the 50 years beginning 1925.

SUMMARY

Model simulations in this study show how forest herbicide management alternatives can be assessed with the GLEAMS model. Alternate herbicide selection and recommended application dates were analyzed for different climatic and soil regions. The study indicates that blanket geographical recommendations should be avoided without similar long-term model analyses. Interactions of soils, slope, climate, and pesticide characteristics affect the environmental window.

This presentation represents only one soil-climatic region with the soil being in the extreme hydrologic soil group A. The same results would not be expected for other soils in other climatic regions. The model applications do show that GLEAMS can be used as a tool to examine the consequences of forest management alternatives.

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